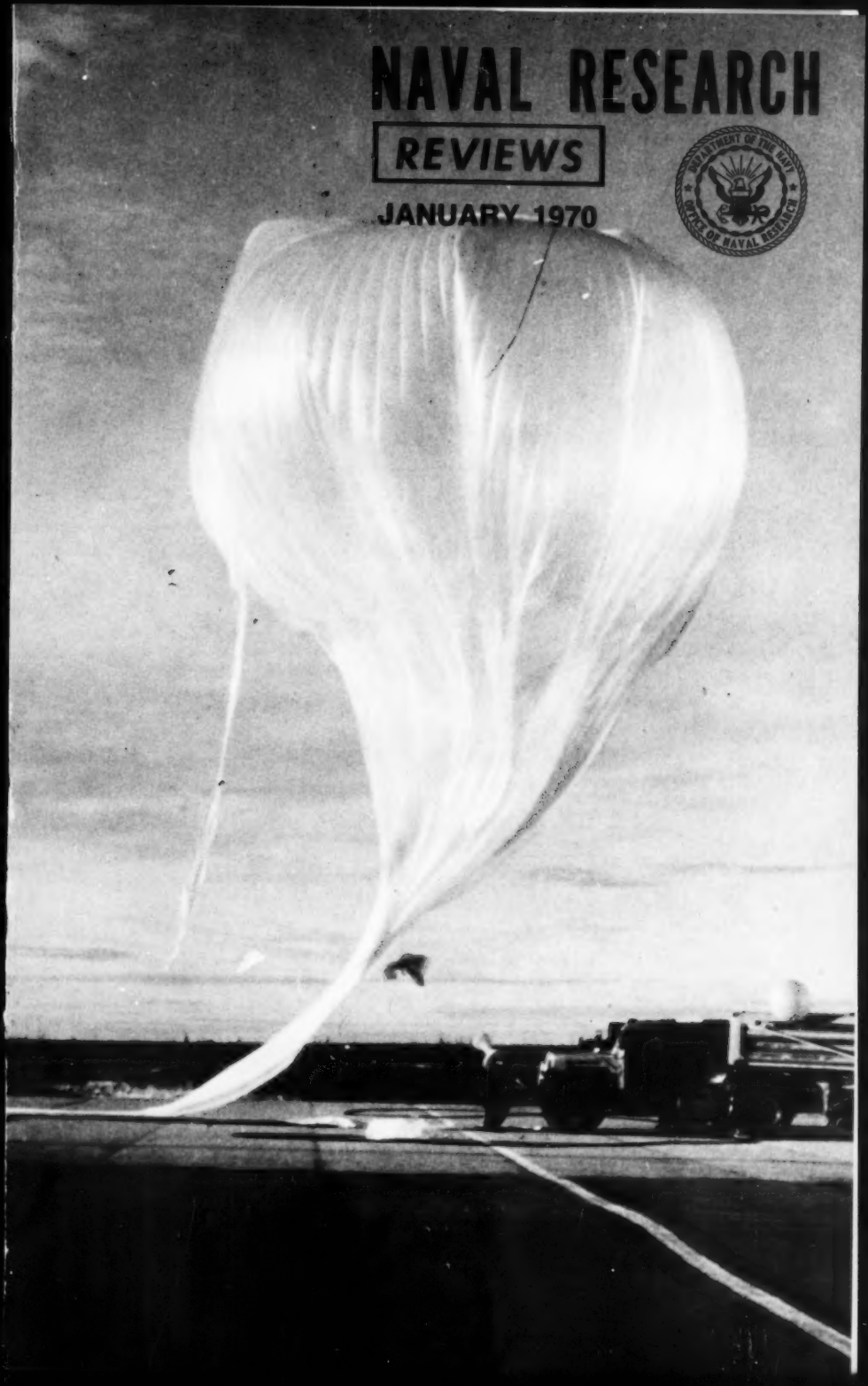
NAVAL RESEARCH

REVIEWS

JANUARY 1970



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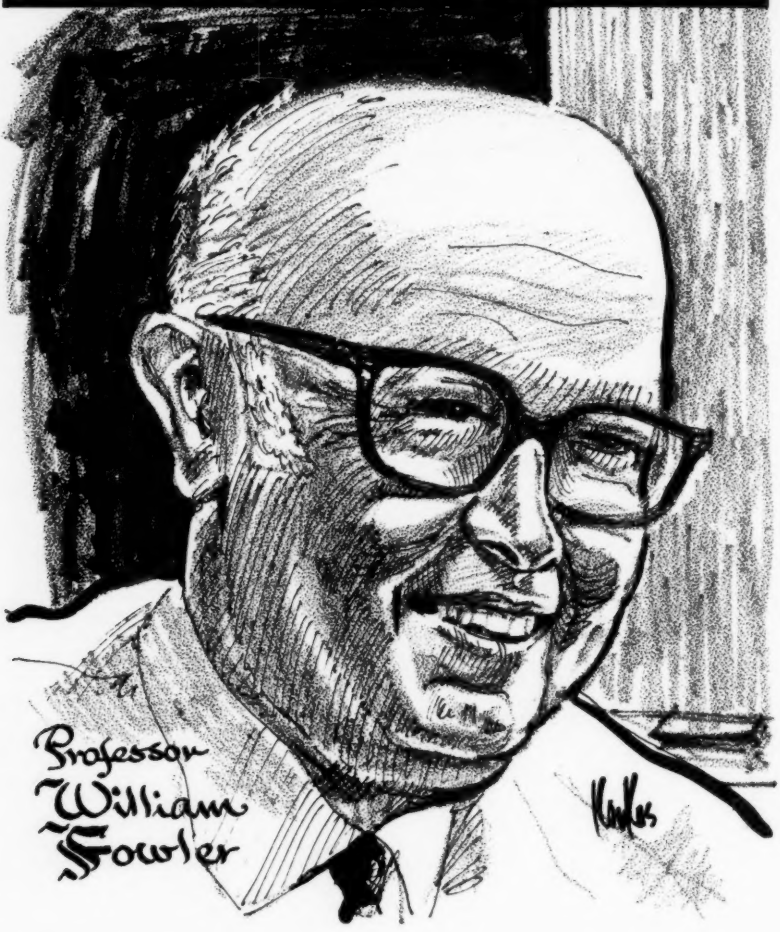
Portraits in Science



AFTER RECEIVING HIS PH.D. FROM CALIFORNIA INSTITUTE OF TECHNOLOGY IN 1936, DR. FOWLER JOINED ITS FACULTY WHERE TODAY HE IS PROFESSOR OF PHYSICS. DR. FOWLER IS WELL KNOWN FOR HIS WORK IN NUCLEAR PHYSICS, ESPECIALLY IN THE FIELDS OF NUCLEAR SPECTROSCOPY, THE STRUCTURE OF LIGHT NUCLEI, THERMONUCLEAR SOURCES OF STELLAR ENERGY, AND ELEMENT SYNTHESIS IN STARS. DR. FOWLER WAS A MEMBER OF THE NATIONAL DEFENSE RESOURCES COMMITTEE AND SCIENTIFIC DIRECTOR OF PROJECT VISTA (DOD). OVER THE YEARS HE HAS HAD CLOSE CONTACT WITH ONR AS A MAJOR CONTRACTOR AND IS PRESENTLY A MEMBER OF THE NAVAL RESEARCH ADVISARY COMMITTEE AND THE NATIONAL ACADEMY OF SCIENCE.

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Designing Displays for Human Use

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Many target detection systems terminate at a cathode ray tube (CRT) designed to display a visual analog of a target to an operator. The visual search task demanded of the operator is frequently a difficult one, and a target may go undetected or may be detected too late. It has been demonstrated that by making relatively minor changes to conventional CRT displays significant increases can be obtained in the probability that a target will be detected.

Cathode ray tube (CRT) displays are employed by the thousands in the Armed Forces, and the great majority of them are used for detecting targets. Detection displays such as radar and sonar PPI (Plan-Position Indicator) displays are characterized by a great deal of visual noise (sometimes termed snow on a TV display). Noise can render the task of visually detecting a target a very difficult one. A marginal target such as a periscope, in a background of noise, can easily escape detection and the consequences can be disastrous.

Efficient visual detection of targets on CRT displays depends, of course, upon the efficiency of an operator's pattern of visual search but, unfortunately, none of the detection displays in use today are designed to encourage efficient search patterns. For several years the Engineering Psychology Branch of the Psychological Sciences Division of ONR has contracted with Human Factors Research, Inc. to investigate and evaluate CRT detection displays which may be superior to conventional detection displays. This is a report pertaining to that research.

Let's imagine a simple experiment in which transient signals are injected, one at a time, onto the noisy trace of an ordinary oscilloscope, at any one of a number of locations from one end of the trace to the other. Each location is used the same number of times and in a random sequence. The signals are just noticeably higher than the highest noise spikes. Now, a subject is seated before the scope and instructed to report every signal he detects and to give its location along the trace.

After a good number of detections have been reported it will become evident that the signals most frequently missed are those located nearest the ends of the trace. In fact, detections at the more central locations will out-number those at either end by about two to one.

The reason is really quite simple. In such a search situation humans tend to search back and forth from one end of the display to the other. Consequently, the location at each end of the display receives just one

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"look" for every two "looks" at the more central locations, and so about half as many detections are made.

Consider the implications of this common search pattern when searching for targets on a conventional early-warning radar PPI such as that portrayed in Figure 1. Operators tend to search back and forth along and behind the rotating sweep-line. In an experiment done some years ago target detections were analyzed in terms of four locations (ranges) along the sweep-line, each location representing a quarter of total range. In the outer-quarter range, where detections give the longest warning, 35 percent of the targets escaped detection. In the third, second and first quarter the percentages of misses were 15, 11 and 37 percent respectively.

The display was modified in such a way as to encourage a different search pattern, one in which the outer-quarter range would be given as many "looks" as the other ranges. This was done by devising a "box-sweep," shown in Figure 2. Subjects were instructed to search in the outer box, the next, the next, the smallest, then start searching again in the outer box, and so on. Such a search pattern eliminates the back-and-forth pattern. At the all-important outer-quarter range, the missed targets dropped from 35 to 17 percent.

The box-sweep resulted in improved detection performance by changing the visual search pattern, another experiment has demonstrated

Figure 1 — A conventional radar PPI

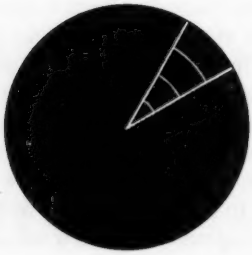

Figure 2 — A radar PPI with a box-sweep

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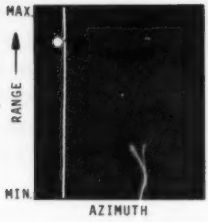

Figure 3 — A conventional radar B-scope

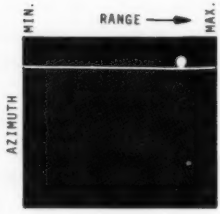

Figure 4 — A B-scope rotated 90°

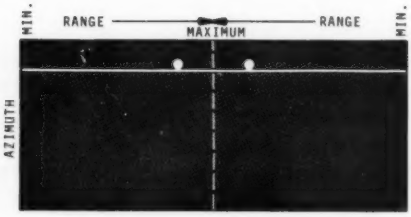

Figure 5 — A mirror-image display

that performance can be improved by capitalizing on the conventional back-and-forth search pattern.

This has been done with a radar B-scope shown in conventional form in Figure 3. Because of the back-and-forth search pattern (up and down in the case of Figure 3), most target detections are made also at medium ranges on this display. The first modification made was to rotate the display 90°, with the result shown in Figure 4. Targets were still detected most readily at intermediate ranges, but the overall percentage of detections was increased because horizontal back-and-forth search is more efficient than vertical up-and-down search. The display in Figure 4 was then "opened up," like a book, so that the right half of the display was a lateral reversal of the left half. This design, shown in Figure 5, is called the "mirror-image" display. Every target was now "painted" twice, and maximum range was represented midway across the display. It was shown experimentally in the outer-third range. Target detection performance was about double that with the conventional B-scope.

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There are airborne radar systems for detecting targets on the surface of the sea that involve another design. Figure 6 represents the PPI display for such a system. It is apparent that the tracks of targets 1 and 2 would each generate a visible chord on the display. Unfortunately, some targets of great interest are extremely small, and they often are undetected because noise is usually present.

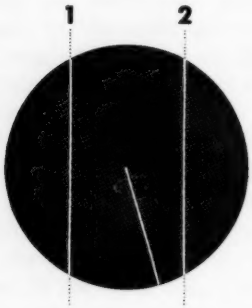

Figure 6 – A conventional PPI with two tracks

Conventional PPIs in such systems are relatively large, frequently 75 square inches in area, and they demand continuous visual search by the operator. If the area to be searched were smaller, the probability of target detection should increase. Also, numerous studies reported in the vigilance literature indicate that frequent rest periods during prolonged visual search result in superior detection performance.

These two desirable features, a smaller area to search and frequent rest periods, can be obtained by designing the display as shown in Figure 7. The two masks, top and bottom, each subtend 120° and consequently the display area remaining to be searched is one-third of that represented in Figure 6. Targets 1 and 2 would be detectable

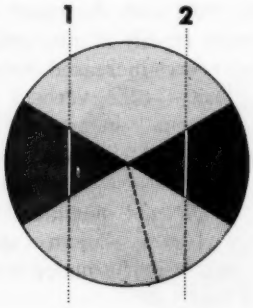

Figure 7 – A bowtie display

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only in the two 60° sectors. It can be seen from Figure 7 that with one exception (a direct fly-over), any target that appears on the display portrayed in Figure 6 will appear in one or the other of the two sectors. It can be seen, too, that for two-thirds of the watch period the sweep-line would be occluded by a mask and the operators could have frequent visual "rest" periods. The display in Figure 7 was termed the "bowtie display."

It was found in the laboratory that 22 percent more detections were made with bowtie display than with the conventional display.

Other aspects of visual search behavior have led to the design of yet another display. Observations of radar PPI operators revealed two facts of importance:

- Visual search is not always confined to the region behind the sweep-line; often display regions searched are far behind the sweep-line where marginal targets have completely faded into the background of noise.
- There is almost continuous eye and head movement on the part of the operator.

The observation that operators frequently search uninformative regions of the display suggested that search performance should improve if these areas were visually denied to the operator. In addition, extensive research done in Holland upon the effect of eye and head movements on visual performance suggested that if a radar PPI was designed to minimize such movements target detection performance should improve.

As a test of these hypotheses, target detection performance was determined using a conventional radar PPI, a PPI which presented only that portion of the display where target detection was most probable and which minimized the eye and head movements required for search.

The three displays are portrayed in Figures 8, 9 and 10. The conventional PPI shown in Figure 8 had a radial sweep-line rotating about the center of the display in a clockwise direction. Figure 9 represents the display designed to mask a portion of the PPI where a circular metal disk with a 90° sector cut out was attached to a metal ring around the PPI. This ring and attached disk rotated at precisely the same speed as the sweep-line, which was continuously in view close to the leading edge of the sector. With this arrangement, a subject could search only the region of the display where the probability of detection was greatest.

Figure 10 represents the display designed to minimize eye and head movements. The sweep-line remained stationary in the position shown and the cathode ray tube rotated in an anti-clockwise direction. The subject's task was simply to watch the region behind the stationary sweep-line.

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Figure 8 — A conventional PPI, clockwise rotation of the sweep-line

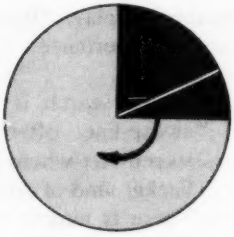

Figure 9 — A conventional PPI, three-quarters masked, clockwise rotation of sweep-line and mask

Figure 10 — A stationary sweep-line, with PPI rotating counter-clockwise

The same cathode ray tube was used for all three displays; a clutch mechanism attached to a radar simulator made it possible to rotate the sweep-line, metal ring, or the cathode ray tube.

It was found that detection performance with the rotating sector display was superior to that with the conventional display, but the best performance was with the rotating PPI. Fifty percent more targets were detected with this display than with the conventional display.

There are numerous situations where search radar is employed to scan only a sector. One such situation is the use of land-based radar for the surveillance of aircraft and shipping to seaward. The large land mass behind the radar is of no interest, yet it is illuminated and displayed on every rotation of the antenna. With an antenna rotation rate of 6 rpm, a target to sea will be illuminated once every 10 seconds. If the 180° of land mass were ignored so that when 180° of sea had been

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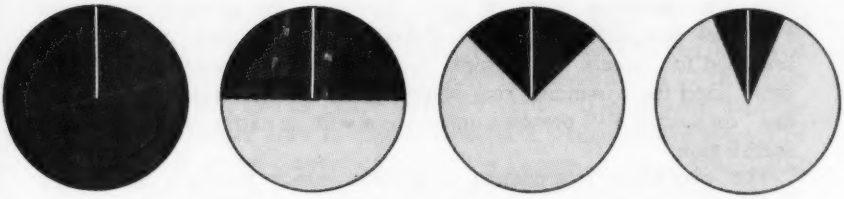

Figure 11 – A conventional PPI and three Continuous Sector Scan displays, of 180°, 90°, and 45° respectively.

illuminated, such as from 270° to 90°, the sweep-line could immediately reappear at 270° and again rotated to 90°. The antenna speed would not have increased, so there would be no loss of radar range, but now the target would be illuminated twice every 10 seconds. Similarly, a sector to sea of 90° would result in four illuminations in 10 seconds, and scanning a sector of 45° would result in eight illuminations in 10 seconds. Such a display has been termed the Continuous Sector Scan; in appearance the sweep-line is like a windshield wiper that always starts it next sweep from the same side the moment the preceding sweep is completed. There are several ways in which antennas could be designed to perform in this manner.

The experiment performed with the Continuous Sector Scan compared target detection performance for the four displays shown in Figure 11, and the experimental data are given in Figure 12. It can be seen that each reduction in the size of the display, and increase in the number of target illuminations, resulted in a rather phenomenal improvement in target detection performance. With the conventional 360° PPI just 10 percent of the targets were detected; with the smallest sector scan of 45°, 78 percent of the targets were detected.

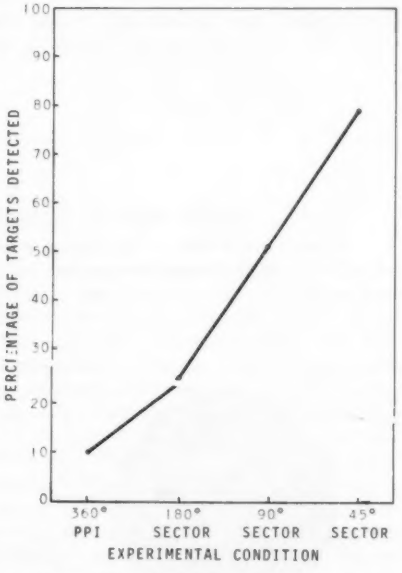

Figure 12 – Experimental data for the four displays shown in Figure 11

When comparing a conventional PPI sonar display to a radar PPI, the conventional radar PPI leaves much to be desired

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from the operating point of view; however, the conventional radar PPI does designate, in a rather awkward way, the area to be visually searched for targets, the general region behind the sweep-line. On the other hand the expanding ring of energy which constitutes the "sweep-line" on a sonar PPI presents an operator with an extraordinarily difficult search task.

The expanding ring-shaped sweep-line which portrays the energy sensed by a sonar scanning switch is, in fact, a spiral. In other words, the phosphor activation displayed on a single ping consists of an extremely long "line" of activity wound in a spiral about the center of the PPI. Such a line of activity can be electronically "wound" in virtually every conceivable manner. It can also be straightened, and thus the wedge display was developed.

Figure 13 — The ring-shaped sweep of a sonar PPI is a spiral

Figure 14 — A sonar wedge display, a target displayed on alternate lines

Figure 15 — A sonar wedge display, a target displayed on adjacent lines

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Consider the exaggerated spiral portrayed in Figure 13. The initial segment AB of the spiral has been straightened in Figure 14 and displayed as A′B′. Similarly, segment BC in Figure 13 is shown as B′C′ in Figure 14, CD as C′D′, DE as D′E′, and EF as E′F′. It is apparent that the successively longer lines in Figure 13 form a wedge-shaped display of 360°. Such a wedge display encourages a pattern of visual search that differs from the spiral display. The lines of displayed energy appear successively in an upward direction, and the search task is one of scanning each line laterally while gradually raising the line of sight.

The two circular spots in Figure 13 and 14 represent returning energy from a sonar target. On the spiral, Figure 13, the target is displayed on adjacent lines, but on the wedge it is displayed on alternate lines.

Because it was not known what effect a display of targets on alternate lines would have upon target detection performance, a second wedge display was developed which would allow the display of targets on adjacent lines. This display can be described by reference to Figures 13 and 15. In Figure 15 the lines forming the wedge represent those spiral segments from the left (180°) side of the spiral display in Figure 13. The target is displayed on adjacent lines. To achieve a display of 360°, it is envisioned that in the normal search mode the display would alternate between any two 180° sectors on successive pings.

This study demonstrates that a sonar wedge display, which presents the operator with a logical search task, is superior to the conventional spiral display. And when subjects were questioned concerning their preference, each without exception preferred the wedge.

Tissue Bank Opened in San Diego

The second major tissue bank in the United States was officially opened on 20 October 1969 at the Naval Hospital, San Diego. Concentrating mainly on procuring skin and bone, this tissue bank should soon become a major source of freeze-dried body tissues for use in reconstructive surgery. The bank collects and stores freeze-dried bone, skin, heart valves, nerves, fascia, and dura (the tough membrane covering the brain and spinal cord). Collected tissues are placed in a liquid nitrogen freezer, operating at minus 212°F., packed in dry ice, and shipped to the Naval Medical Research Institute (NMRI) in Bethesda, Maryland, for the freeze-drying process. Once freeze-dried, human tissue can be stored without special care for indefinate periods of time. The important freeze-drying process also eleminates antigenicity, making donor-recipient matching for compatability unnecessary. After this process, the tissue is returned to San Diego. The feasibility of extending the San Diego facility's capabilities to include freeze-dry processing will be determined later.

NMRI in Bethesda remains the only other tissue bank besides San Diego in the Western Hemisphere; both are run by the U.S. Navy. The other three operating tissue banks in the world are located in Birmingham, England; Warsaw, Poland; and Prague, Czechoslovakia.

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Liquid Lasers

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Lasers provide a systems designer with intense and well-collimated beams of monochromatic electromagnetic radiation spanning the spectrum from near ultraviolet to far infrared. Two categories of devices can be distinguished; those producing a continuous wave (cw lasers), and those emitting either single or repetitive pulses. The range of output in terms of power and energy is very large; cw lasers have been operated at levels of hundreds of watts, whereas pulsed lasers have produced short pulses lasting 10^{-11} with peak powers of the order of 10^{12} watts or relatively long pulses (several milliseconds duration) with an energy content of thousands of joules.

Today's lasers often fall short of achieving specifications involving such factors as frequency range, stability, reliability, efficiency, cost, size, mode of operation (pulsed or cw), peak power, average power, and beam divergence. In response to such needs and out of his own inquisitiveness, the laser researcher has produced a large variety of materials covering all three phases of matter (solid, both crystalline and amorphous; gaseous; and liquid). ONR has been very active in the development of liquid lasers. During the initial phase of laser activity (1960-1963), there were no liquid lasers. This was due to the fact that the early attempts were unsuccessful. There was speculation that liquid lasers could not be made because of the poor optical qualities generated in the liquid medium during the excitation pulse. However, in 1963 under ONR sponsorship, a liquid laser was operated at the General Telephone and Electronics Laboratories by Lempicki and Samelson (1). The compound they used was a chelate,* europium tetrakis benzoylacetonate, dissolved in a mixture of ethanol and methanol. At first laser action was achieved only at low temperatures where the solution is said to "glass." In this sense the first liquid laser might be considered another glass laser. However, within a few years a substantial number of other europium compounds, all chelates, were made to lase in a variety of solvents. The temperature at which laser action could be obtained continued to increase until the phenomenon could be observed at room temperature. A true liquid laser was achieved in a system in which the laser medium was circulated. Important contributions to this work were made by the group at GT&E (2) and by Schimitschek and his coworkers (3) at the Naval Electronics Laboratory in San Diego.

*Type of compound in which the active rare earth ion (europium in this case) is at the center of a large "cage" made of organic molecules.

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It became apparent that as long as the materials were limited to the chelates used with europium, the devices, having high thresholds and low output, were of limited usefulness. Attempts to overcome the material limitations were unsuccessful, and interest in this kind of liquid laser waned.

The need to develop satisfactory liquid lasers remained because liquids are inexpensive, and solutions are relatively easy to prepare in quantity, and the components are readily recoverable by standard chemical techniques. These advantages compare favorably with the cost and difficulty of producing laser quality crystals and glasses in large volumes. The cooling problems inherent in high-power and high-energy applications, either with high repetition rate or cw laser operation, are much simpler with liquid than with solid state lasers; instead of having to remove heat by the efficient process of circulating a coolant around the active laser component, the laser solution can be circulated and efficient heat exchangers and mixers can be employed. Another advantage for liquid lasers is that it is difficult for them to suffer permanent damage, providing it is photochemically stable, while the solid-state materials are susceptible to damage in high-power and high-energy devices.

The continued research in liquids split into two directions. The first, carried out at the General Telephone and Electronics Laboratories worked in rare earth ions; the second, principally conducted at IBM, revived an earlier effort in the use of organic fluorescence and carried it to a successful conclusion under the leadership of Dr. P. P. Sorokin (4). Organic liquid lasers, like gas lasers, have an enormous frequency range over which they can operate. In addition, each individual compound can be tuned over a frequency range of one-hundred angstroms or more. The complete story of the organic liquid laser would require an extended treatment, and should be treated separately. This paper will confine itself to the inorganic liquid laser.

New Liquid Materials—How to Use Them?

Overlapping the work on the europium chelate lasers, there was a renewed interest in the general problem of fluorescence in liquids. The work of Robinson and Frosch (5), Windsor (6), Gallagher (7), and Heller (8) indicated that the presence of hydrogen atoms was intimately connected with the quenching of fluorescence in solutions. Heller was able to show that the OH or hydroxyl group was principally responsible for the quenching of the fluorescence of rare-earth ions in solutions. For some rare-earth ions chelation, which results in surrounding the rare-earth ion with oxygen atoms, was sufficient for shielding the ion from the quenching influence of the OH group present in the solvents.

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Then, as in the case of europium, laser action could be achieved. However, for most ions of the rare earth series, this is not sufficient and the OH group common to nearly all solvents for ionic materials would quench the fluorescence.

What was required was a solvent which not only did not contain hydrogen but in addition had a reasonably high dielectric constant. The search for such a solvent centered on the class of inorganic oxychlorides; the prime candidate was selenium oxychloride with a dielectric constant of 46. This solvent did indeed dissolve a limited amount of some neodymium salts and produce solutions which exhibited significant fluorescence. Concentrations of neodymium high enough to realize a practical device were obtained when Lewis acids such as antimony pentachloride ($SbCl_5$) or tin tetrachloride ($SnCl_4$) were added to the solution.

The $SeOCl_2$-$SnCl_4$ solvent system is, however, corrosive and toxic; only a few materials such as quartz, pyrex glass, and to some extent teflon are resistant to it. This factor hindered the rapid development of inorganic liquid lasers and spurred the research for other solvent systems. Recently, systems were developed based on a second oxychloride, $POCl_3$ (9-12). This solvent is somewhat less corrosive than the selenium oxychloride system and substantially less toxic. It also does not corrode high purity alumina, aluminum and nickel.

Much of what can be expected from a laser material can be deduced from spectroscopy of the material alone without the necessity of making a laser. The fluorescence emission spectra of $POCl_3$ and $SeOCl_2$ systems

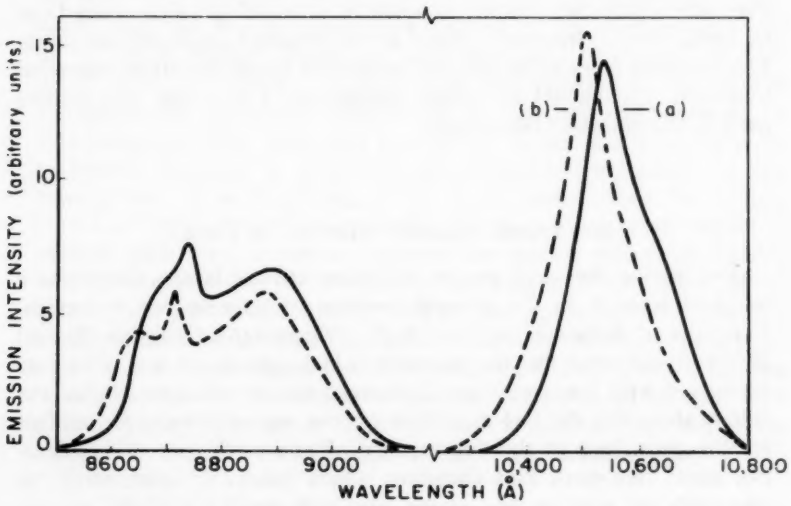

Figure 1 — Fluorescence spectrum of Nd^{+3} in: (a) $SeOCl_2$ and (b) $POCl_3$

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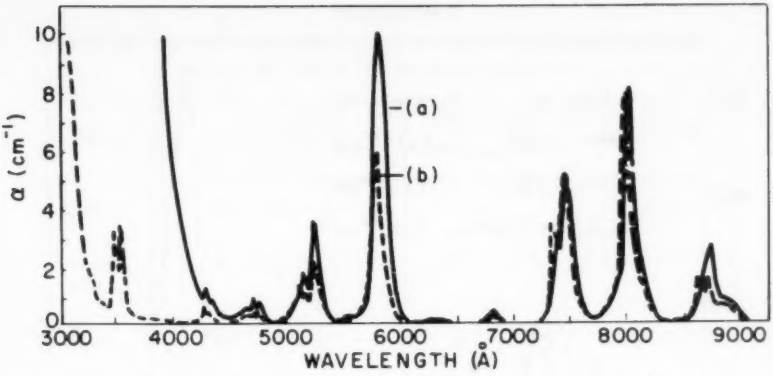

Figure 2 — Absorption spectrum of Nd^{+3} in: (a) $SeOCl_2$ and (b) $POCl_3$

are compared in Figure 1, and the absorption spectra in Figure 2. Although in broad outline, these two systems are comparable, in detail there are some differences. Figures 3 and 4 compare the spectra of Nd^{+3} in $SeOCl_2$, $CaWO_4$ crystals and laser glass. Calcium tungstate ($CaWO_4$) crystals could be operated cw, but this material is somewhat inferior to the currently used yttrium aluminum garnet (YAG); the laser glass data are from a sample obtained during the early stages of glass development. The laser liquid is seen to resemble glass in that it has broad absorption and emission lines. A deeper insight can be obtained from a comparison of the absorption cross sections for the dominant fluorescence lines (in the region of 1.06 μ) which constitute the laser transition. The gain of the laser is proportional to this cross section; it can be determined from spectroscopic measurements of fluorescence intensity, line width, and decay times. Comparative values of cross section for a number of Nd^{+3} laser materials are given in Table 1. It is seen that liquids have cross sections intermediate between those of YAG and glass. This has important consequences for the type of laser application which can most profitably utilize liquids.

Laser oscillation always occurs when the gain or build-up of stimulated emission is large enough to overcome the inevitable losses due to scattering in the material and the partial transmission of the output mirror. For cw lasers the gain has to be high because continuously operating excitation light sources have a brightness far smaller than that of pulsed flash lamps. YAG crystals are therefore superior for this type of application. They are not particularly good for pulse operation requiring output energies in excess of about 1 joule per pulse. Glasses, which have low cross sections (and the consequent high thresholds for laser oscillation) are more advantageous when large energy (of the order of 1 kilojoule) pulses are desired.

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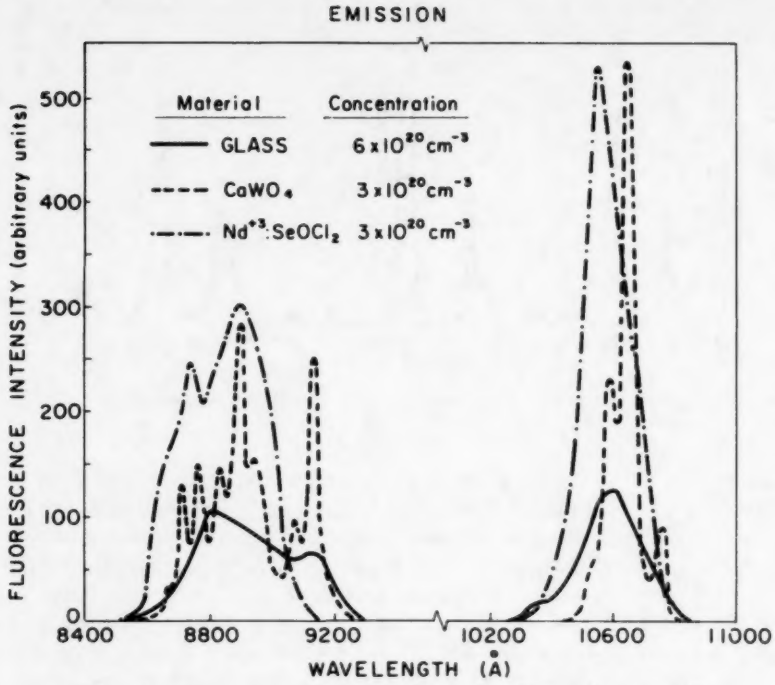

Figure 3 — Fluorescence spectrum of Nd^{+3} in three different host materials

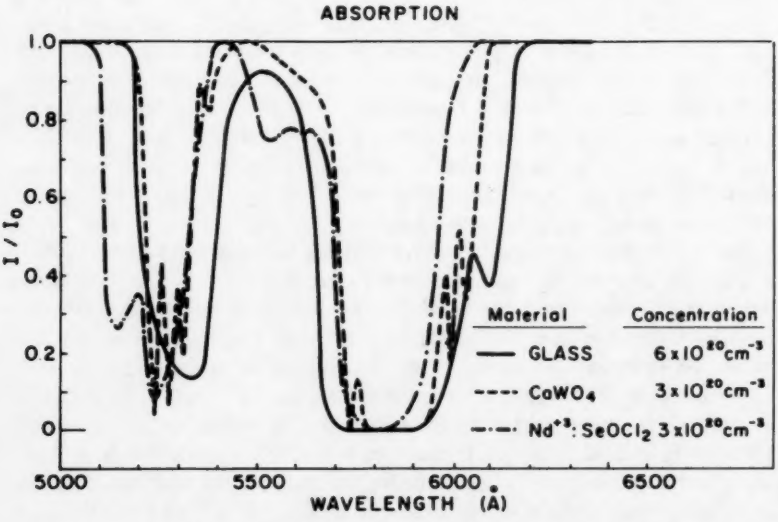

Figure 4 — Absorption spectrum of Nd^{+3} in three different host materials

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TABLE 1
Comparison of absorption cross sections* and fluorescence decay for Nd^{+3} ion in various media.

Medium	Absorption Cross section (cm^2)	Decay Time (Milliseconds)	Reference
YAG	$27 - 90 \times 10^{-20}$	0.24	14,15,16
Aprotic Solvents	$6 - 8 \times 10^{-20}$	0.25 – 0.4	12,17
Glass	$0.3 - 3 \times 10^{-20}$	0.1 – 1.0	18,19,20,21

*For the $^4F_{3/2} - {}^4I_{11/2}$ transition.

Many system applications call, however, for an intermediate type of operation, namely repetitive pulses (1 to 10 per second) with energies of 5 to 50 joules per pulse. This is equivalent to average powers of 5 to 500 watts. In this regime YAG crystals fail on account of their limited energy storage ability (per pulse), and glass fails because of heat dissipation problems. This is the most natural domain for liquids, one where the intermediate cross sections and ability to circulate the medium can be turned to best advantage.

State of the Art

How close we come to attaining the goal of a high average power device can be seen from a brief review of the available information on liquid laser performance and the direction the work is taking. To achieve the desired repetition rates, the design of the liquid laser system must involve circulation of the amplifying medium through the resonator and this requires an elaborate system. However, in operation such a device is merely a repetition of the single pulse, static experiments. Thus the two aspects, laser investigations and circulation techniques are separable, and the laser information can be obtained from static experiments using the simple laser cell illustrated in Figure 5. The cell is filled with the liquid and used in the same type of flash enclosure as, say, a glass rod. The basic experiment is the measurements of the pulse energy output as a function of electrical energy input. The parameters in these experiments are the cavity mirror transmission, the geometry of the laser sample, and such properties relating to optical pumping as flash lamp pulse length and coupling technique. From the data obtained the dynamic loss and efficiency can be derived.

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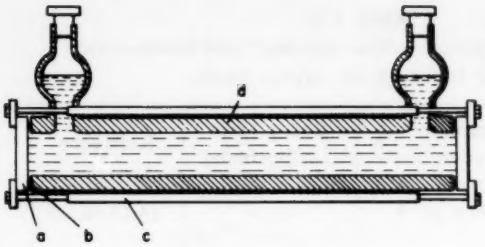

Figure 5 — Demountable liquid laser cell.
(a) Cell window.
(b) Teflon coated silicone O-ring.
(c) Invar or stainless steel tie rods.
(d) Cell body.

An example of such data for several different mirror transmission is shown in Figure 6; the slope efficiency and the threshold are immediately available. In the example shown here, the slope efficiency varies from 0.4 to 0.6 percent depending on mirror transmission. This efficiency is relatively low (the experiment was designed for other purposes) but slope efficiencies of 0.4 percent are readily obtained from liquid lasers. The threshold can be regraphed as a function of the mirror reflectivity, as shown in Figure 7, to provide information on the dynamic loss. In the case shown here the loss is 0.0012 percent per centimeter. This value is typical of $SeOCl_2$ laser solutions and compares favorably with results on YAG and glass. The low loss value points out the high optical quality that can be obtained from liquids at exceptionally low cost. It is

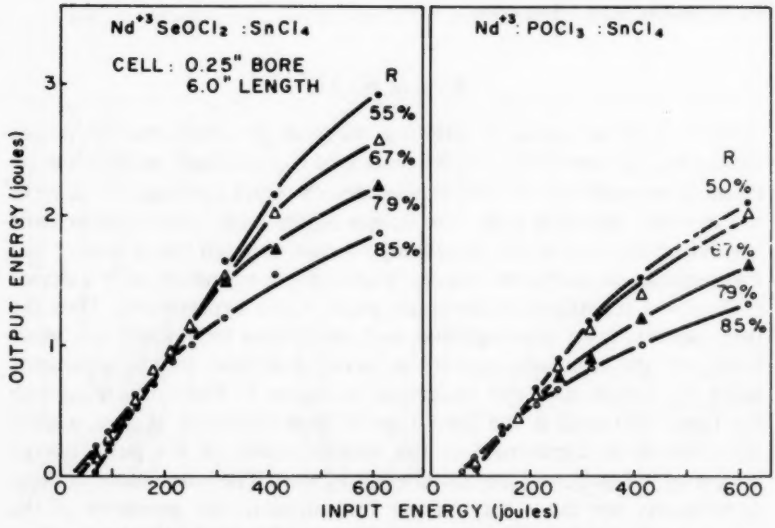

Figure 6 — Output energy as a function of output energy for various output mirror reflectivities R

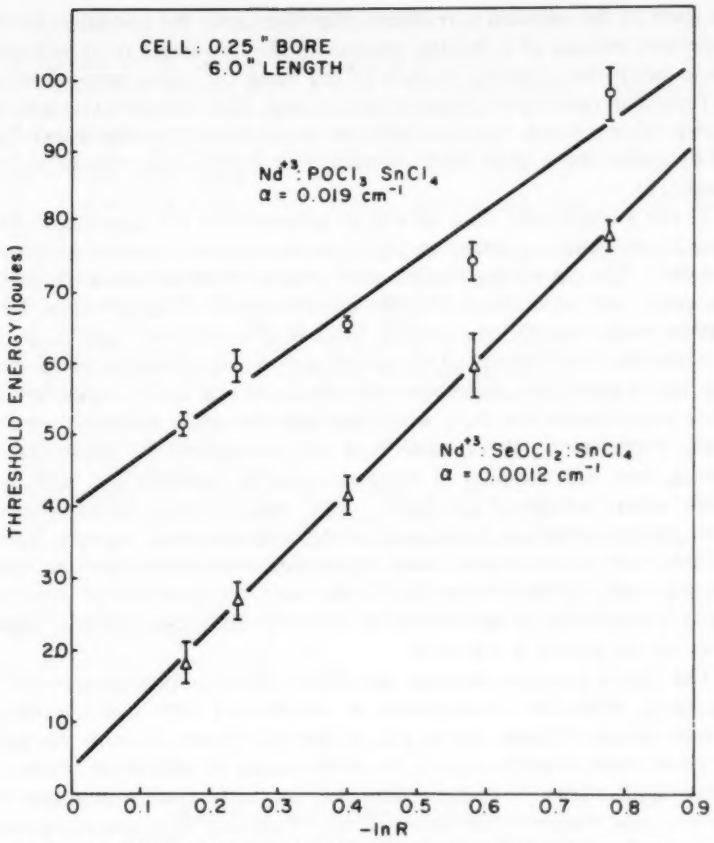

Figure 7 — Threshold energy as a function of output mirror reflectivity. The values of α are the dynamic loss coefficients obtained from these data.

a result not entirely unexpected since liquids are free of all the loss-producing imperfections common in solids such as inclusions and strains.

The interesting and encouraging aspect of this low loss is that the heating of the solution by the flash does not result in major optical distortion. One might have expected such distortion because the temperature-dependent change in refractive index is typically a hundred times larger for liquids than for solids. This distortion is indeed easy to detect if we attempt to flash the laser again within a period of seconds or even a few minutes; the performance is then much poorer. The important fact is, however, that the thermal loss sets in after the laser pulse is over. If one were able to replace the solution in the resonator with new material, all at the same temperature, the second flash could be repeated

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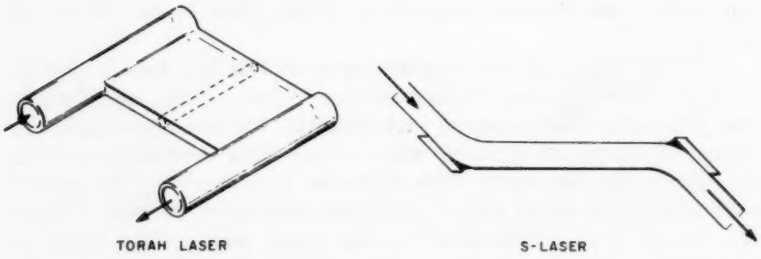
as soon as the solution is replaced. This is exactly the condition for the repetitive pulsing of a flowing system. In the first series of experiments on a circulating system, outputs of 0.1 joule per pulse were obtained at repetition rates up to 20 pulses per second. This represents an average power of two watts, which is only ten times lower than the upper limit of operation for a glass laser consisting of a single rectangular slab of glass (13).

These experiments only served to demonstrate the practicality of a liquid laser with a circulating active medium; many improvements are possible. The circulating pumps used in these experiments were barely adequate and were affected by the corrosiveness of the solutions. New pumps made entirely of materials inert to the solutions (quartz, pyrex and alumina) have recently been developed. A second feature component capable of significant improvement is the laser cell. In the initial flowing laser experiments the cells were basically the same as those used in static experiments. While such cells are satisfactory for static experiments, they are marginal in systems requiring uniform and high flow rates under isothermal conditions. New cells are now being designed with greater attention being paid to the hydrodynamic aspects. These include both conventional axial types similar to those used in static experiments and transverse flow types with the potential of obtaining rapid replacement of laser liquid for high repetition rate systems. These cells are illustrated in Figure 8.

The liquid laser is entering the phase where a practical device is emerging. With the development of satisfactory cells and circulating pumps inorganic liquid lasers will, in the near future, become competitive and quite possibly exceed the performance of solid-state devices in some applications. It appears than that the laser system designer will have a new device at his disposal, in the area of high average power. There is, however, much fundamental research to be done. The fluorescence of liquid presents many unsolved and fascinating problems upon which many future laser improvements may still depend.



(a) Transverse flow *(b) Axial flow*

Figure 8 — Schematic drawings of cells with improved hydrodynamic properties. These are now in the design stage.

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Analysis of Lunar Samples by ONR Contract Program Investigators

The front page of the *Washington Post* for Saturday, November 8, 1969 contained an article in which Dr. Harold Urey reported the age of the moon to be 4.5 billion years. Dr. Urey's statement was based on the preliminary results of analysis of Apollo 11 lunar samples by Dr. G. J. Wasserberg at the California Institute of Technology. Wasserberg's analysis was based on mass spectrometer measurements of the rubidium (87)/Strontium (87) ratio. The half life of Rb^{87} is 50 billion years and a comparison of the abundance of Rb^{87} to its decay product Sr^{87} allows age dating of specimen which are some billions of years old. It is interesting to note that Dr. Wasserberg is one of the ONR scientific investigators under Professor W. A. Fowler. Much of the facilities used in the analysis of the lunar samples by this group have been provided by our contract.

It is anticipated that many of the more significant results of the analysis of lunar material will derive from mass spectrometer studies. Mass spectroscopy provides the most accurate and most sensitive methods for studying minute traces of elements found embedded in bulk materials. Mass spectroscopy has been pioneered and perfected under ONR contract at the University of Minnesota by Professor A. O. C. Nier. This group is also involved in lunar material analysis. Thus we anticipate some of the best scientific studies of the Apollo 11 lunar samples will also contain an ONR credit line.

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Linear-Accelerator Research at Stanford University

CDR. M. E. Toms, USNR
Naval Research Laboratory

After World War II, Professor W. W. Hansen returned to Stanford University where, prior to the war, he had invented the cavity resonator and the Varian brothers had invented the klystron. These inventions were aimed at developing a new method of accelerating electrons. With the establishment of the Microwave Laboratory, Professor Hansen and his colleagues were concerned largely with accelerators and with klystrons as power sources for them. This research was initially supported by ONR and later by a Joint Services contract. The objectives of the Laboratory have always been to provide a suitable environment for basic research, to provide facilities for the training of graduate students, and to provide a source of technical ideas and assistance to the Department of Defense.

As the investigations at Stanford have been in the forefront of the development of linear electron accelerators, the effort in improving needed components and perfecting their manufacture has been a major and continuing function of the Microwave Laboratory. The design of electron guns, improvements in resonant-cavity waveguides and the development of klystrons have necessitated detailed investigations and have resulted in widespread benefits to basic nuclear physics, to DOD needs, and to industrial applications. The electron gun development broke away from the established Pierce design and used analytic methods, by means of a computer, to obtain electron-gun geometries which produce higher beam convergence ratios. These methods were also used for designing guns for magnetron amplifiers.

Pulsed klystrons, able to produce multi-megawatts of rf (radio frequency) power, were first built at Stanford. Much of the knowledge concerning high-power klystrons gained from the basic research effort prior to the Korean War was of direct and immediate value to DOD. The rapid utilization of these research results was possible because the Joint Services contract permitted free unchanneled research and the cooperative effort of another laboratory in transforming the research into practical devices. Continued development has produced klystrons of high efficiency and long life. As an outgrowth of the klystron development, similar techniques were used to produce and evaluate high-power travelling-wave tubes and electronic circuits for them. Such circuits are in use for ground transmitters for communication with satellites.

Linear electron accelerator development progressed under Navy and other agency sponsorship from the first 6-Mev linac to the 1-BeV, Mark III, linac. This effort provided the basic technology needed to build the two-mile accelerator under AEC sponsorship. The Mark III was used extensively for nuclear physics research and was used by Professor Hofstadter to make the Nobel-Prize-winning measurement of nucleon size. The Stanford technology is the basis of development of electron linacs in this country. People trained at Stanford have had a major role in commercial companies that build linacs and their components. Two linacs supported by the Navy, at Gulf General Atomic and at the Naval Research Laboratory, are used for basic nuclear physics which contributes to knowledge of relevance to Navy needs. Linacs have been used in research programs related to military needs, and also in industrial radiography, food sterilization and cancer therapy.

At Stanford, with ONR support, the first "sealed-off" linac was developed for cancer therapy. This linac installed at the Stanford University Hospital was mounted so its position could be varied as needed for patient irradiation. As the aim in cancer therapy is the destruction of malignent cells with the least harm to normal tissue the use of 6-Mev x-rays was a big improvement over 200-Kev x-rays previously used for treatment. Klystrons and accelerating wave guides for two higher energy linacs for cancer therapy were constructed at the Stanford High Energy Laboratory.

More recently, the ONR-sponsored research at Stanford has centered on the development of a superconducting linac. As before, Stanford is pioneering a new field for which the technology has to be developed. The advantage of a superconducting linac over the standard kind is achieved by the greatly reduced surface resistance of the accelerating cavities at very low temperatures, thus decreasing the rf power loss in the waveguides. The resulting high gain or Q of the cavities permits a greater acceleration per unit length and a reduction in input power which allows duty cycles of 100 to 1000 times greater than those of conventional linacs to be achieved.

Relationships governing the operation of resonant cavities at superconducting low temperatures differ from those for room-temperature accelerating waveguides. Investigations in detail have been made to determine the optimum frequency, the mode of operation and the superconducting material from which to make the cavities. A prototype of the capture section made with cavities of lead electroplated on copper has been operated and used with a superconducting beam separator to measure beam characteristics. Research with cavities made of niobium shows this material, when properly processed, to be superior to the electroplated lead and technology for fabricating the final cavities has been perfected. This research opens the possibility of building superconducting beam separators with duty cycles which can match those of

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proton synchrotrons, superconducting rf cavities for electron synchrotrons and microtrons. Such cavities can be used in extremely stable tunable oscillators that are expected to be important for communications and guidance systems. A very sensitive magnetometer using a double superconducting loop is being developed.

The large-scale low-temperature technology developed for this linac can have important applications for the Navy. Because of the unique properties of superfluid helium, it is possible to distribute the refrigerant over lateral distances of several hundred feet and vertical heights of over 50 feet.

A strong interest in Stanford's superconducting-linac research was expressed at a meeting on "Negative pi-mesons in Radiotherapy," held at Stanford University Medical School last July. Biophysicists have been considering the use of negative pions instead of x-rays, electrons or protons for the radiation treatment of cancer patients. The negative pions have very low ionizing power along their flight paths so that their effect on normal tissue can be minimal. The lengths of their flight paths are dependent upon the initial kinetic energy of the particles; hence, their depth of penetration can be controlled. At the end of their paths they are captured by an atomic nucleus. The rest-mass energy produces a disintegration with the ejection of highly ionizing charged particles of short range. Thus the high radiation damage is localized in the desired volume. Present accelerators produce pion-beams of insufficient intensity for cancer therapy. It has been estimated, however, that a proton superconducting linear accelerator could be designed specifically for radiation therapy with a length of 75 to 100 feet and would produce a pion flux sufficient to produce a dose of 100 rad/min.

Under the ONR Nuclear Physics contract, Stanford is the leader in efforts to combine microwave and low-temperature technologies. Although this technology is being developed for application to accelerators, its contributions in other areas is just beginning, to be realized.

Submilliter Waves, March 31-April 23, 1970, at Commodore Hotel, New York City. Polytechnic Institute of Brooklyn Symposium. Sponsored by the Air Force Office of Scientific Research, Office of Naval Research and the Army Research Office. For information contact Major H. W. Jackson, Air Force Office of Scientific Research (SREE), 1400 Wilson Blvd., Arlington, Va. 22209. Tel. Area Code 202, 694-5565.

Mathematical Conference on Several Complex Variables, April 5-17, 1970, at University of Maryland, College Park. International Conference. Sponsored by the Air Force Office of Scientific Research and the Office of Naval Research. For information contact Major W. R. Trott, Air Force Office of Scientific Research (SRMM), 1400 Wilson Blvd., Arlington, Va. 22209. Tel. Area Code 202, 694-5264.

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The Submarine That Saves Its Crew

Ben L. Friedman
Office of Naval Research

The modern submarine, which is one of the better weapon systems in the country's arsenal, has one major failing—there is no effective solution to the problem of crew rescue. As ocean technology expands, the submarine is capable of going deeper and deeper, making the problem of crew escape even more critical.

The Office of Naval Research is working on a concept which will hopefully materialize into a submarine which can rescue its own crew. The unique feature of this concept is that the escape system is an integral part of the vehicle design and is not dependent on outside help from a rescue vehicle.

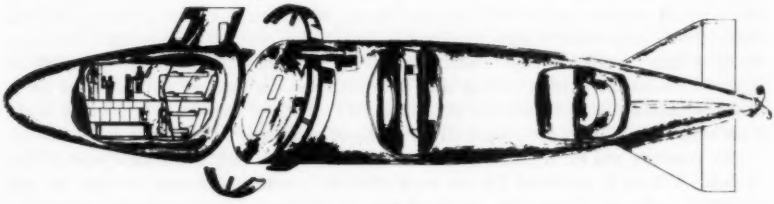
The objective of the ONR study is to determine the feasibility of incorporating a self-contained jettisonable module, which separates from the main body of the submarine and rises to the surface, thus providing escape for the crew. The concept should operate at any depth eliminating the customary air and surface search by rescue forces.

Some of the limiting factors of present day submarine rescue methods which ONR hopes to improve are:

- Detecting and locating a disabled submarine, particularly below a safe pressure depth where distress signals can't be released.
- Conducting air and sea searchs.
- Using rescue vehicles which must successfully couple with the disabled submarine, an operation which depends upon a series of related factors; any one of which can abort the entire operation.

A better understanding of the concept is gained by referring to the drawing, which shows that the forward portion of the submarine is jettisonable from the main body of the submarine, and when separated will rise to the surface. The separation can be accomplished in several ways. The drawing shows a ring clamp in a released position which allows the forward and aft section to be separated. The ring clamp can be released electromagnetically, hydraulically, or by an explosive charge.

The forward module houses the entire crew at all times and serves as the main control center for operating the vehicle. All systems (machinery, weapon, hydraulic, circulating, propulsion, electronic, and electrical) will be controlled and operated from the forward module. Entrance into the aft section will be



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permitted for periodic maintenance, repair, and inspection. The further development of integrated systems and remote control, quick disconnect devices mounted internally or externally to the pressure hull will permit separation of all connectors and lines.

The current ONR study is directed toward defining the requirements for an escape capability for the crew of a submarine. However, in the future the concept may expand to become a self propelled, multi-purpose vehicle which can be separated from the main body of the submarine and become a detachable-attachable vehicle operating on the surface or submerged as a survey vehicle, replenishment vehicle, a research vehicle, or a salvage vehicle. The modular concept has a decided advantage in that the forward section can be separated from an obsolete vehicle and reattached to a modern vehicle. The concept and study is being closely coordinated with the Navy's submarine development and operational agencies.

Oxygen Release from Hemoglobin

The part of the red cell which carries oxygen is a chemical called hemoglobin. Oxygen molecules attach to hemoglobin across the lung wall, and when the red cells reach the tissues, oxygen diffuses from the hemoglobin into the cells of the tissues. One factor that influences how many of the red cells pick up oxygen in the lungs is the partial pressure of oxygen. If the partial pressure is lower than that normally required for the full saturation of all the red blood cells, a situation which occurs at high altitudes, then the body attempts to produce a compensation to provide the full amount of oxygen needed by the tissues. This compensation was thought to be an increase in the number of red blood cells. However, it is known that some people cannot adjust to living at high altitudes even though they manufacture so many red blood cells that they may develop circulation disorders. Under ONR sponsorship, Dr. Brewer, Department of Human Genetics, University of Michigan, Ann Arbor, Michigan, has discovered that an increase in red cells is not the most efficient compensatory mechanism. His data show the compensation is centered, not on the amount of hemoglobin, but rather on how fast oxygen dissociates from the hemoglobin when it gets to the tissues. This dissociation is primarily controlled by the amount of a compound in the red cell called diphosphoglyceraldehyde (DPG), which presumably participates in a reaction to unbind oxygen from hemoglobin.

Dr. Brewer designed and built an apparatus which measures the rate of oxygen release of whole blood. Using this machine on the blood of people living at high altitudes (10,200 feet), he found that there was a slower dissociation of oxygen, and a low DPG level was correlated with a fast dissociation. Thus those that had to make excessive red cells did so because they were unable to increase DPG levels. Dr. Brewer's evidence makes possible the prediction of how well certain individuals can adjust to high altitudes based on their normal red cell levels of DPG. He notes that anemic (low hemoglobin) blood has increased DPG levels as a compensatory mechanism. Other consequences of this research involve the effects of smoking on the DPG levels of blood and the effects of blood storage on DPG levels. Past studies show a subnormal rate of dissociation of oxygen at normal hemoglobin levels in heavy smokers. This is probably due to the affinity of the carbon monoxide in cigarette smoke for oxygen binding sites in hemoglobin. Dr. Brewer will study the DPG levels of smokers and how altitude affects the DPG levels of smokers. He will also study what happens to DPG levels when blood is stored and when stored blood is transfused.

This research will be of great value to aviation personnel and to Marine Corps at high altitude. A basis is provided for the most efficient selection of people to work at high altitude. In addition, future data on blood storage will be of interest to medical facilities.

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Research Notes

Navy Studies Control of Termites Without Insecticides

A research program aimed at controlling harmful insects without the use of persistent chemicals, such as DDT, has been undertaken by the Navy. This has led to two methods that hold promise for destroying termites more efficiently then by the use of insecticides.

The Navy is concerned about serious damage caused by insects and other organisms to its property and equipment. In the case of termites, they cause damage estimated in the millions of dollars to Navy installations around the world, particularly in the Pacific area. Although the Department of Agriculture is normally concerned with this research, the Navy has prime responsibility for pest control in overseas areas where major Navy bases are located.

The new methods for controlling termites were originated by the University of Hawaii and the University of Wisconsin, which are developing them under contracts with the Office of Naval Research. One method is to introduce into the termite nest certain micro-organisms which then multiply and destroy the colony. The other method uses a "Pied Piper" approach in which the termites are tricked into following a trail that leads to a death trap.

The primary target is the Formosan termite, a species that is very common in tropical climates. It attacks all types of wood and cellulose products, and under conditions of low moisture feeds on growing trees and other plants. In Hawaii, where the Navy has extensive installations, it is the most destructive agent of wood buildings. It even frequently disrupts telephone communications by penetrating and infesting underground circuits. The species has found its way to the continental United States and has been recorded in Texas, Louisiana, South Carolina and other locations.

Millions of termites in a colony live in underground galleries that cannot be easily reached by insecticides. When termites are detected outside the nest, the insecticides kill them immediately. This means, however, that the chemical is not brought back to the nest to act against the colony.

The University of Hawaii has developed in the laboratory a technique which involves treating the termites with strains of fungi and also pathogenic nematodes which carry bacteria that destroy termites through parasitic action. Initial laboratory tests show that the parasites kill the termites in periods ranging from 12 hours to 14 days. This provides ample time for the termites to return to their nest and "seed" the colony with the organisms. The moist warmth of the termite galleries in the nest is an ideal medium for the parasites to multiply and eventually destroy the colony. With Navy support the university will conduct field tests using this method.

The "Pied Piper" approach still under development at Wisconsin makes use of a social characteristic of the termite. Certain termites are known to secrete a "trail-marking" chemical that serves to guide the members of the colony to points where food is available or in colony migration or to repair damaged walls. It is hoped that by obtaining a chemical extract from this one type of termite it can be used to lay a trail to a trap where the termites can be easily destroyed.

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New Research Vessel

The blue and gray, 245-foot, 2075-ton *Melville*, the nation's newest oceanographic research vessel, recently joined the fleet of Scripps Institution of Oceanography. The *Melville* becomes the largest ship in operation for Scripps, next in size being the veteran of many extended expeditions, the 213-foot, 2079-ton *Argo*.

The ship was put through her paces during extensive trials in the Bahama Islands area. These included a thorough test of her unique cycloidal propulsion system and machinery, including winches and other deep-sea gear.

The *Melville*, which has a maximum capacity of 62 scientists, technicians, and crew members, is named for the late Rear Adm George Wallace Melville, Arctic explorer, hydrographer, and Navy chief engineer. She will be equipped for research in biological, geological, physical, and chemical oceanography.

The vessel will be used initially in local operations by Scripps scientists to familarize themselves with the ship's facilities and general operating characteristics.

The *Melville* has a sustained sea speed of 12 knots and a cruising range of more than 10,000 miles. She has a beam of 46 feet and a full-load draft of 15 feet. She is powered by a slow-speed, 2500 horsepower engine, has three Diesel ship's service generators with a total capacity of 800 kilowatts, and can distill 6000 gallons of fresh water daily.

Special features of the *Melville*, in addition to the cycloidal propellers, include:

- A bulb-like viewing port that extends from the bow, housing sonar equipment for undersea mapping and having viewing ports for scientists.
- An 8-by-10-foot well that makes it possible to conduct coring and drilling operations through the hull.
- Capability of carrying six portable, prefabricated vans. These vans can be fitted out for any one of three functions: as laboratories, as explosives magazines, or as living quarters, each housing four persons. They can be preloaded and bolted to the ship's deck. Portable vans make for quick turn-around time in port and a ripid interchange of scientific programs.
- Deck equipment that can handle the launching, servicing, and stowing of 15-ton vehicles, deep-sea submersibles, deep moorings up to 20 feet in diameter and multi-tone transducers for acoustic experiments.
- Capability of towing large vehicles, such as FLIP, Scripps' Floating Instrument Platform, or unmanned, 40-foot buoys.
- Four completely independent laboratories, including a scientific chart room and operations center.
- All machinery has been designed and will be installed for minimum vibration.

Another Balloon Record

The world's largest single cell polyethylene balloon was launched November 15, 1969 from Longreach, Australia. The balloon's volume was in excess of 30 million cubic feet. Arrangements and coordination for this flight were made by the Office of Naval Research. A Melbourne University research team is working on the experiment with Case Western Reserve University, Cleveland, Ohio. The purpose of the flight was to search for cosmic gamma-rays with energies above 30 MeV. The prime objective of a southern hemisphere flight is to observe the intense extended source of gamma-rays in the direction of the galactic center. This represents a first in southern hemisphere ballooning in regard to the weight of the scientific payload and the size of the balloon. The scientific package which

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weighed 450 pounds was maintained at 156,000 feet. The flight was terminated by radio command from a tracking aircraft and the payload was expeditiously recovered by the crew from the Australian Balloon Launch Station.

Navy to Play Important Role in TEKTITE II

The Navy will play an important scientific role in TEKTITE II, which will be conducted for seven months beginning next spring off St. John, Virgin Islands. Aquanauts will live and work on the ocean bottom during that time for periods of two to four weeks.

TEKTITE II will be a cooperative effort involving both government and private organizations, with the Department of Interior serving as the lead agency. The Navy was the lead agency for TEKTITE I, in which four aquanauts conducted a record-breaking two-month mission earlier this year.

The TEKTITE II program will include a major marine scientific mission and extensive human behavioral and biomedical studies. The Navy through the Office of Naval Research will coordinate the biomedical phase of the operation and cooperate with the National Aeronautics and Space Administration in the behavioral studies. University scientists under contract to ONR in conjuction with NASA scientists will monitor the TEKTITE aquanauts and analyze the biomedical and behavioral data. This information will provide additional understanding of the problems associated with small crews living in isolation for extended periods under stressful conditions as may be encountered in space exploration and undersea missions.

One significant mission will be to operate a small two-man habitat at 100 feet to determine whether nitrogen/oxygen breathing mixtures can be safely used at these depths. This will be the longest saturation dive yet made in the ocean at such depths using a nitrogen/oxygen mixture.

In addition to participating in the scientific program, the Navy through the Naval Ship System Command's Supervisor of Salvage will provide some logistics support to the operation.

Others supporting the TEKTITE II program include the National Science Foundation, the Government of the Virgin Islands, the Smithsonian Institution, the National Institutes of Health, the U.S. Coast Guard, and the Environmental Science Services Administration. In addition, several universities will participate. These include the College of the Virgin Islands, the University of New Hampshire, the University of Texas, and the University of Rhode Island.

The General Electric Company, which designed and built the TEKTITE habitat, is again providing it for program use and will furnish engineering support for the operation.

The main habitat supporting the primary research will be located at a depth of 50 feet. In all, ten separate operation phases are planned. More than 50 scientists and engineers will participate as aquanauts in the ocean floor program. They will be drawn from various government agencies and universities and also from other countries.

In addition to the marine scientific, behavioral and biomedical programs, new equipment and techniques will be developed and evaluated for increasing man's performance in carrying out undersea scientific missions. These will include oceanographic instrumentation, underwater communications and navigation equipment, swimmer propulsion systems, and long-duration closed-cycle SCUBA devices.

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On the Naval Research Reserve

NRRC 11-7

Can sewage be made potable and will the public accept and use such water? This was the subject of a presentation to Naval Reserve Research Company 11-7, Tucson, Arizona by Gordon Davis, Chief Field Research Engineer of the City of Tucson Water Utility on 16 October 1969.

Tucson's water reclamation project envisions using reclaimed water first for fishing and boating, then recreational swimming, and finally for domestic use. This research and development is being funded by the Federal Government, the University of Arizona, and the City of Tucson.

NRRC 11-11

In its pursuit to maintain a viable organization, Research Reserve Company 11-11, Santa Monica, California, has reaffirmed its policy of presenting outstanding speakers relating to both Navy and civilian interests. Without neglecting the naval and technically oriented objectives of the Research Program, and considering the interrelation between military and civilian sectors, a new dimension has been added. Recognizing the responsibility that all personnel be aware of, understand and contribute toward the solution of the urgent social and environmental problems of our population centers, the theme, "Problems of the Expanding Megalopolis," was chosen the past year.

The success of the program has been evidenced by nearly 100 percent attendance by members of the company. Future programs will emphasize the impact of technology, its utilization and potential in contributing to solving not only military but social problems.

NRRC 11-19

U.S. Naval Research Reserve Officers in the greater Los Angeles area received a briefing sponsored by NRRC 11-9, at the North American Rockwell Downey Plant of the Apollo 10 space shot on 17 May, the day prior to the actual shot. The briefing included the Apollo flight plan from lift-off, through lunar orbit, to splash-down. A visit was also made to CBS studios at the North American Rockwell plant to see how separation and docking maneuvers were simulated for television viewing during space flights.

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Free-Fall Electromagnetic Current Meter

A free-fall device, capable of measuring the horizontal velocity of ocean currents at any or all depths in the sea has been developed by Dr. Thomas Sanford, Woods Hole Oceanographic Institution, an investigator under ONR Contract. The device measures the induced electric field associated with ocean currents passing through the geomagnetic field of the earth.

The instrument is a 7-foot, 6-inch I.D. pressure cylinder with fins. The electric field is measured as the voltage between the ends of opposite fins. The fins are pitched so the instrument will rotate as it falls through the water—allowing the magnitude of the induced electric field to be measured at various orientations, and, hence, the current vector to be measured. The electric field measured is proportional to the difference between the horizontal velocity at depth of measurement and the vertically averaged velocity at the location, with an accuracy of the order of 1 cm/sec.

The operation of the instrument at sea is relatively simple. As the instrument freely falls through the sea the information on how the horizontal velocity varies with depth is acoustically telemetered back to the ship and displayed on the PDR. The signals consist of a reference time pulse and delayed pulses giving pressure, electric field magnitude and a north reference. When the instrument strikes the bottom, a weight is released and the instrument returns to the surface, repeating the measurements as a "free-rising" device.

The first set of measurements with the instrument were recently taken in the Gulf Stream. The results show that the measured electric field is in good agreement with theoretical predictions. Horizontal velocity profiles, with a measurement every eight meters, were made to the bottom (4400m). It took approximately one hour to make a profile. The profiles showed a "fine structure" in the velocity reminscent of the "fine structure" or "layering" now seen in temperature with the STD probes. Future plans call for incorporating temperature in the freefall current meter. In addition to measuring current structure these electromagnetic measurements may provide a very useful means of studying the motion of internal waves.

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IN THIS ISSUE

VOL. XXIII, NO. 1

Designing Displays for Human Use ..... C. H. BAKER 1

By making minor changes to conventional CRT displays, the probality that a target will be detected will be greatly increased.

Liquid Lasers ..... H. SAMELSON, A. LEMPICKI 10

Under ONR support a liquid laser was developed and may soon emerge as a practical device. Because liquids are inexpensive and solutions are easy to prepare in quantity, there is a need for the liquid laser.

Linear-Accelerator Research ..... CDR M. E. TOMS 20

Under the ONR Nuclear Physics contract, Stanford is the leader in efforts to combine microwave and low-temperature technologies. Although this technology is being developed for application to accelerators, its contributions in other areas is just beginning to be realized.

Research Notes 25

On the Naval Research Reserve 28

The balloon, which is being launched in the cover picture, is very similar to the one which recently set a record in Australia. *See Page 26.*

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